RHIC

BROOKHAVEN NATIONAL LABORATORY

Presentation to the NSAC Subcommittee

Overview

S. Aronson

4/4/05

15	Praveen Chaudhari	Director's remarks
25	Sam Aronson	Overview
25	James Nagle	Experiment Status-Heavy Ions
25	Miklos Gyulassy	Heavy Ion Physics
25	Robert Jaffe	Spin Physics
25	Abhay Deshpande	Experiment Status-Spin & eRHIC
25	Axel Drees	Detector Strategy
25	Thomas Roser	Facility Strategy
25	Thomas Ludlam	Operations Scenarios
25	Larry McLerran	QCD & RHIC

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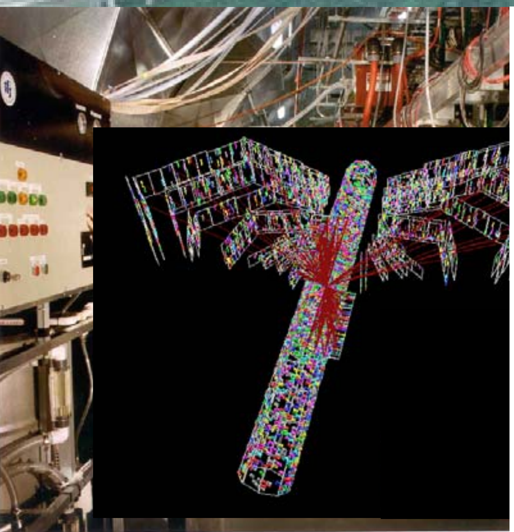
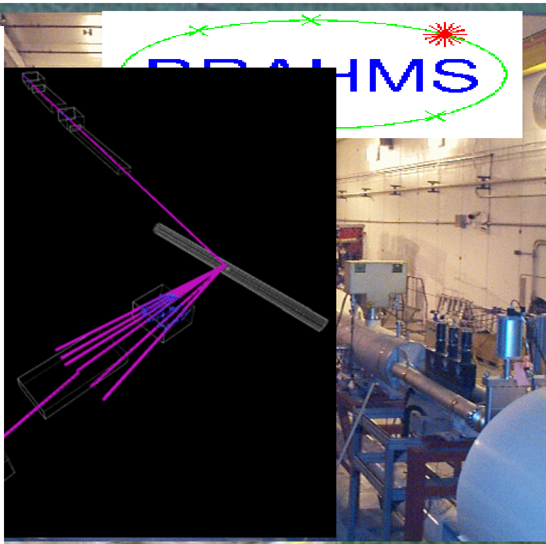
Outline

- Our vision of the RHIC complex over the next decade and beyond
- Accomplishments to date
- Some key science questions to be addressed
- Budget Challenges

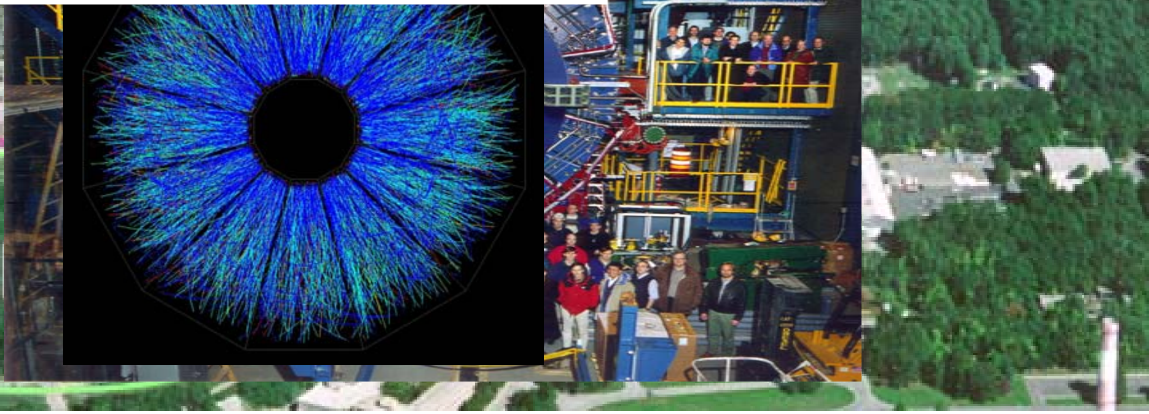
RHIC's Experiments





- 7 coupled accelerators
- Nucleus –nucleus collider from 20-200GeV/nucleon
  - Symmetric or asymmetric species
- Polarized proton-proton collisions up to 0.5TeV

- Both capabilities are unique world-wide



A vision of the RHIC complex

- Discoveries at RHIC ⇔ Compelling questions about QCD
  - The nature of confinement
  - The low-x and spin structure of hadronic matter
  - The structure of quark-gluon matter above T_C
- Compelling questions ⇨ evolution of the Facility
  - High integrated luminosity & proton polarization
  - New detector capabilities

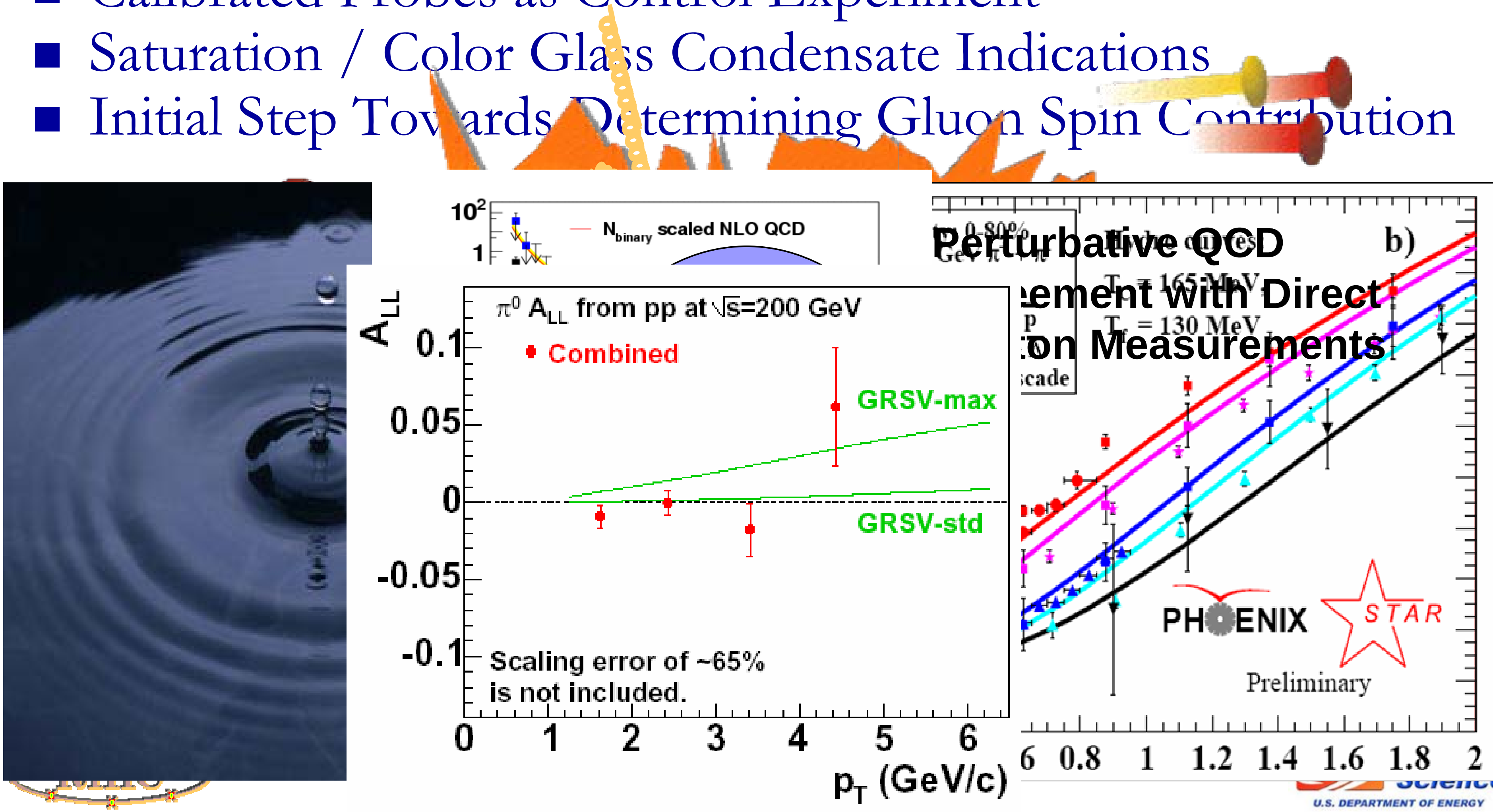
  RHIC II
  - eRHIC: e-A and polarized e-p collisions and detector
  - 50-fold increase in lattice gauge computing power applied to finite temperature QCD

RHIC – Major achievements, 2001-present

- 4 complementary experiments BRAHMS, PHENIX, PHOBOS STAR
  - Concordance among their results is a hallmark of the program
- 5 annual runs to date
  - Au-Au, (polarized) p-p, d-Au, Cu-Cu
  - Several energies, $20 \leq \sqrt{s_{NN}} \leq 200$ GeV
  - Tremendous scientific impact: 105 published refereed experimental research papers (66 in PRL), >5000 citations, 65 more submitted or in preparation
- 3-year retrospectives submitted for publication by the 4 experiments
  - What have we discovered at RHIC?
  - What are the questions that now compel our attention?

Major experimental discoveries and advances

- Discovery of “jet quenching”
- Discovery of “close-to-perfect liquid” behavior
- Calibrated Probes as Control Experiment
- Saturation / Color Glass Condensate Indications
- Initial Step Towards Determining Gluon Spin Contribution



What have we learned?

- We've learned we can do definitive studies of QCD at high energy density in the laboratory!
- These measurements tell us the following about the matter produced at RHIC:
  - Energy density > 5 GeV/fm^3, T ~ 200 MeV achieved
    - Sufficient to induce phase transitions
    - Consistent with production from initial state with gluon saturation
  - Thermalizes very quickly, exhibits highly collective motion consistent with hydrodynamic models (very low viscosity)
    - Close-to-perfect liquid
  - Extraordinary parton energy loss ~10GeV/fm –

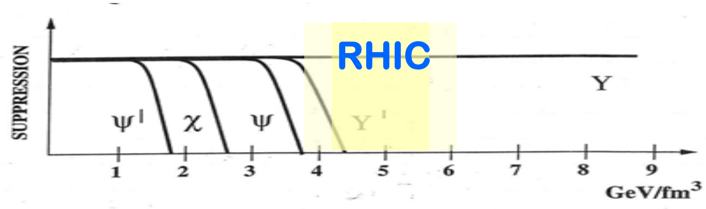
    ~Opaque to partons, ~transparent to leptons and photons

What do we want to know?

- The nature of confinement
  - What is the nature of the phase transition?
  - Is chiral symmetry restored?
- The low-x and spin structure of hadronic matter
  - Is the initial state a Color Glass Condensate?
  - What is the spin structure and dynamics inside the proton?
- The structure of quark-gluon matter above T_C
  - How does the thermodynamic character of the collision evolve so rapidly from the initial state?
  - What are the properties of the medium?

What is required?

- ***Key measurements***
  - **Hard probes** created very early in the collision and propagate through the medium. Their interactions with the medium sensitive to how the medium is created
  - The main observables:
    - **high-p_T particles** and jet fragmentation
    - **hidden charm** (J/ψ production)
    - **open charm** and bottom quark production



  - **Electromagnetic probes** (either real or virtual photons) Large mean free path ⇨ no final-state interaction: direct information about the medium's properties.
  - Main observables: **low-mass e^+e^- pairs** and **thermal radiation** of the medium
  - **Polarized proton collisions** (W-production at $\sqrt{s}$=500GeV for sea quark flavor selection)
- Operations at the FY2005 level (~31 cryo-weeks/year) ⇨ we can address these questions in the 5-10 year time frame
  - Systematic species and energy scans (this has proved crucial!)
  - Balance of running RHIC ***and*** investing in upgrades

Funding scenarios

- Optimized program is 31 cryo-weeks/year and includes upgrades
- Constant effort funding starting with the President's budget in FY 2006 ⇨
  - Running across fiscal year boundaries (run every other year)
  - Limited investments in the future (upgrades slow down)
  - Reduced operations staff (40 FTEs in response to the 2006 President's budget)
- Flat-flat funding at the FY 2006 President's budget level would effectively end the program in 5 years

RHIC in the context of Nuclear Physics, Science and Society

- Tremendous scientific impact: 105 experimental papers >5000 citations, and a comparable body of theory papers
- RHIC is an outstanding educator of nuclear physicists:
  - The four RHIC experiments have produced 98 Ph.D. students (51 US). The rate of Ph.D. production is still increasing
  - According to the NSAC Report "Education in Nuclear Science,"
    - RHI is the largest of 10 Current Research Areas for all demographic groups in Nuclear Science (men, women, US Ph.D.s, US citizens, etc.)
    - RHI is the research area where the largest cohort of current post docs in Nuclear Science got their Ph.D.s
- ~10 OJI and PECASE awards to junior RHIC scientists

RHIC in the context of Nuclear Physics, Science and Society

- Tremend … papers
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- RHIC is … cists:
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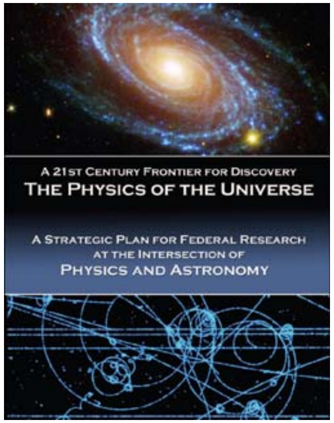
- RHIC Physics has significant overlap with other active areas of fundamental research
  - **High Energy Density Physics – *"Physics of the Universe"*** lists among its Summary Recommendations:

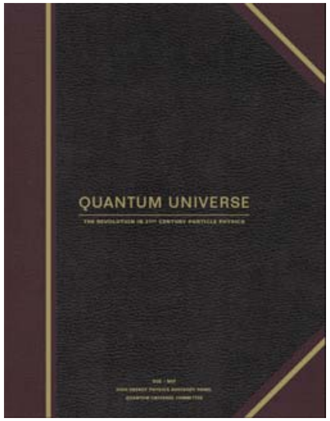
    "High Density and Temperature Physics….

    * DOE and NSF will develop a scientific roadmap for the luminosity upgrade of The Relativistic Heavy Ion Collider (RHIC) in order to maximize the scientific impact of RHIC on High Energy Density (HED) physics."

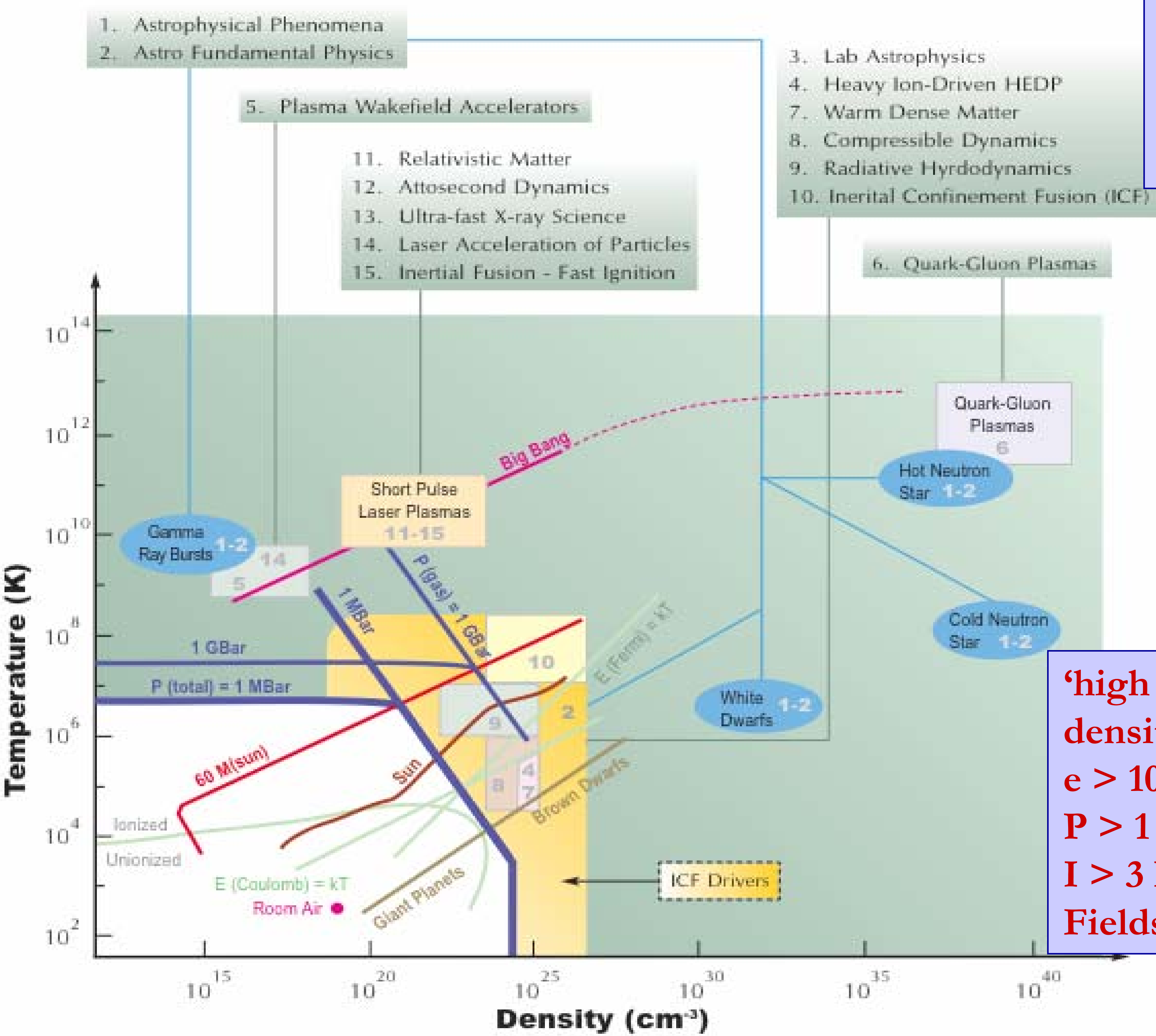


  - **Particle Physics** – QCD!
  - **Early Universe – *"Quantum Universe:"***

    "Currently, the most intensely studied cosmic phase transition is connected with quantum chromodynamics (QCD)…. During the QCD phase transition, the baryonic matter in the present universe condensed from a plasma-like state of quarks and gluons. The Relativistic Heavy Ion Collider (RHIC) facility at BNL is currently creating collisions of heavy ions to study quark-gluon plasma…. Lattice Computational Facilities will enable calculations furthering the understanding of the RHIC data and the conditions during this epoch in the evolution of the early universe."



Map of the High Energy Density Universe:



'high energy density':

$e > 10^{11}$ J/m^3

P > 1 Mbar

I > 3 X 10^{15}W/cm^2

Fields > 500 Tesla

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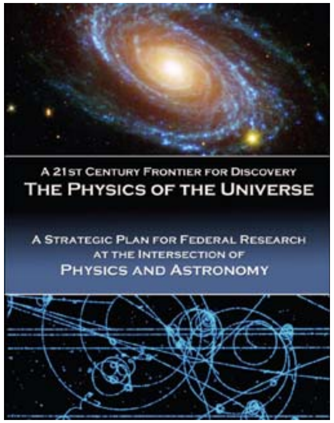

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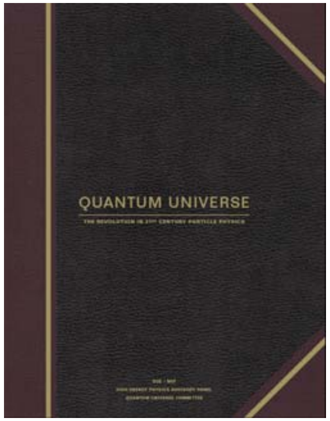

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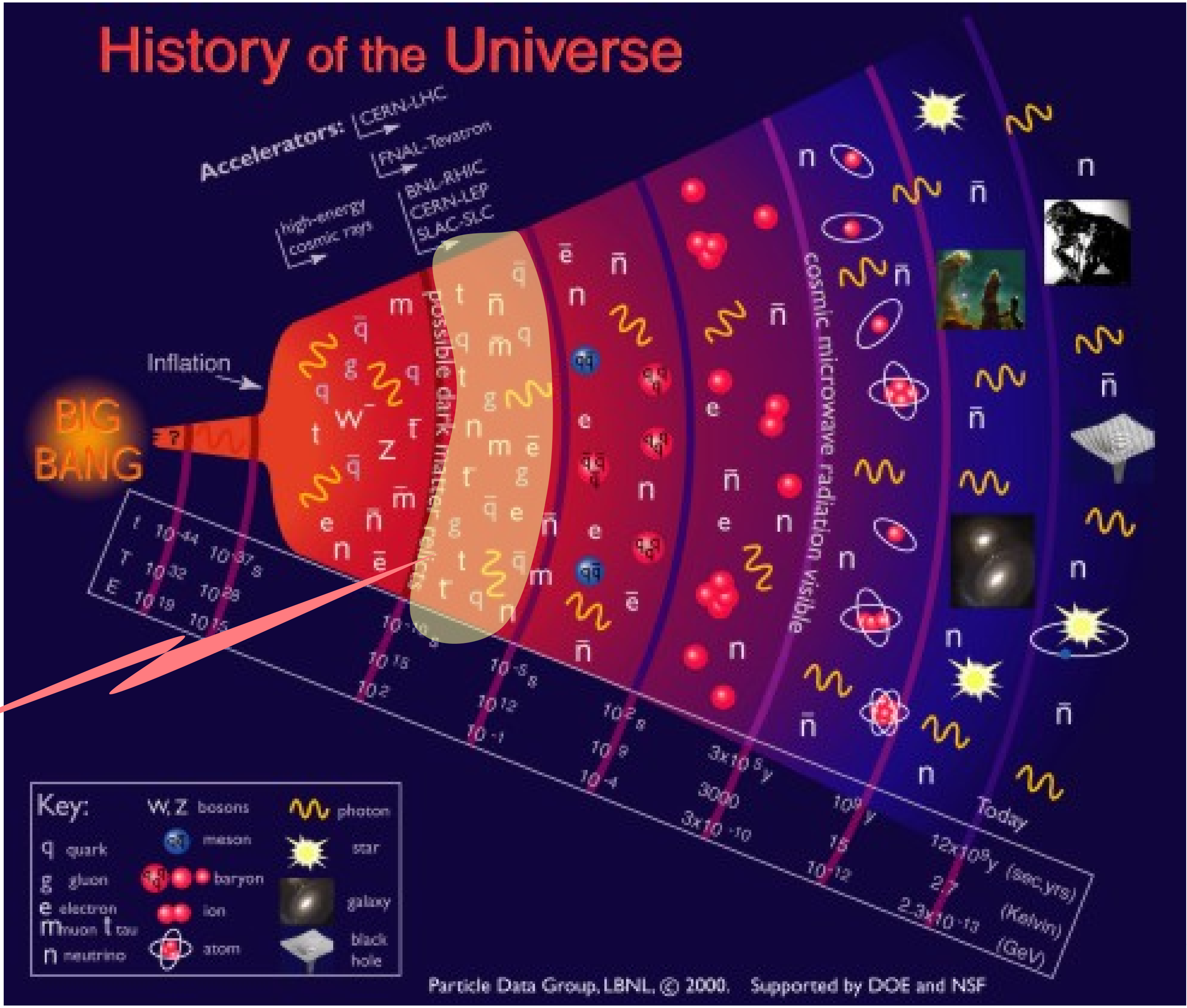
The Thermal Universe

- 10 GeV/fm^3 ~ 10^{16} gm/cm^3
- T ~ 170 MeV ~ 2 x 10^{12} K
- Conditions that prevailed ~ 10 μs after the Big Bang



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RHIC ~~or~~ and LHC

- LHC is not a replacement for RHIC - they complement each other
  - **Collision Energy**
    - RHIC probes high energy density in the central region. The initial state (gluon saturation) is probed in the forward regions (low x)
    - LHC's higher energies make high p_T jets and heavy quarks more accessible.
  - **Dedicated, flexible facility**
    - RHIC provides exploration vs. system size and energy, in hot and cold nuclear matter + p-p in the same detector. EBIS will extend the A-range to U
    - At RHIC **QCD is the prime objective**
  - **Unique capabilities with a future**
    - **Unique spin program** aimed at some of the biggest hadron physics problems. There is a path forward leading to a polarized DIS collider facility (eRHIC)
  - **US Leadership Role**
    - The US has leadership in this exciting area - great momentum and excellent teams to do the physics and train the next generation
    - Just beginning to reap the benefits of a massive investment (people & funds)
    - The US RHI community will also work at the complementary LHC facility

Summary

- RHIC is a very exciting arena of Nuclear Physics research that is just reaching its prime
- The exploration of high energy density physics at the energy density frontier is a "hot topic" with impact in science, scientific education and public science awareness
- This is an area of world leadership in nuclear physics for the US and the DOE
  - Host to an extensive and highly committed international collaboration with major non-US contributions
- From a science perspective the future looks very bright - there is a natural path that leads to fundamental research in broad areas of QCD